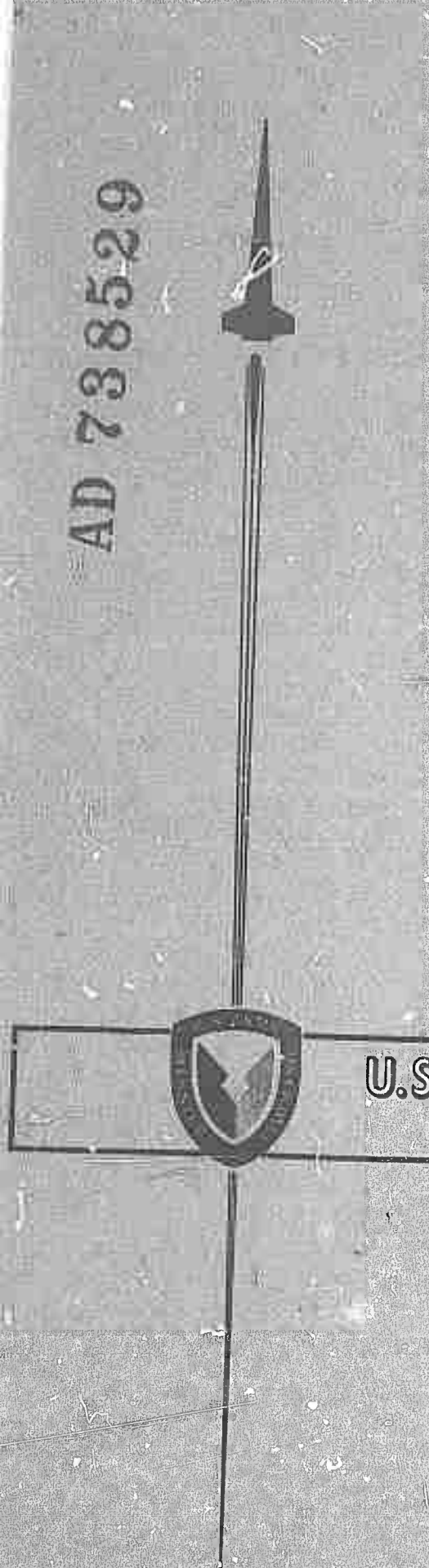



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# FIELD EFFECT ELECTRON EMISSION

by

Joe Shelton

August 1971



U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama

Sponsored in Part by Materials Sciences,
Advanced Research Projects Agency,
Arlington, Virginia 22209

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13. ABSTRACT

The emission of electrons from materials at ambient temperature due to the field effect is a subject of extensive study and experimentation. Although large current densities, greater than 100 $A\text{-}cm^{-2}$, have been realized from sharp points, few commercial applications have resulted because of the problems associated with fabricating multiple point sources. Recent developments in fabrication procedures have resulted in multiple point sources of sufficient size and uniformity to be applicable to electronic devices such as electron tubes which require a copious supply of electrons for operation. Current densities of near 100 $mA\text{-}cm^{-2}$ have been realized from early samples, indicating that these new multiple point sources emit electrons in sufficient numbers to replace thermionic emitters in several classes of electron tubes.

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## ABSTRACT

The emission of electrons from materials at ambient temperature due to the field effect is a subject of extensive study and experimentation. Although large current densities, greater than 100 A-cm$^{-2}$, have been realized from sharp points, few commercial applications have resulted because of the problems associated with fabricating multiple point sources. Recent developments in fabrication procedures have resulted in multiple point sources of sufficient size and uniformity to be applicable to electronic devices such as electron tubes which require a copious supply of electrons for operation. Current densities of near 100 mA-cm$^{-2}$ have been realized from early samples, indicating that these new multiple point sources emit electrons in sufficient numbers to replace thermionic emitters in several classes of electron tubes.

## 1. INTRODUCTION

The generation of electrons for electron tubes and other applications has been the subject of extensive study and experimentation. The majority of the effort has been concentrated in the field of thermionic emitters rather than in field effect emitters because of the lack of techniques for fabricating field effect emitters of sufficient size for the majority of applications.

## 2. DISCUSSION

The need for an electron emitter other than the thermionic emitter results primarily from the problems associated with the heat generated by the thermionic emitter. In most cases, it is essential to rigidly support the emitter. The support in turn conducts the heat to other parts of the device and must eventually be removed from the device to prevent temperature increases that would cause catastrophic failure. The magnitude of the temperatures encountered with thermionic emitters can be seen by considering the classical expression

$$J = 2A_oT^2e^{-e\phi/kT}$$

where

$J$ = current density

$A_o$ = constant

$T$ = absolute temperature

$k$ = Boltzmann's constant

$e\phi$ = work function

If we consider this equation in conjunction with the lowest work function emitters that are compatible with the other device components, we find that an operating temperature of near 800°C is required for current densities of approximately 1 A-cm$^{-2}$. In addition to the usual problems associated with this high temperature, such things as emitter-heater isolation and outgassing become major problems for devices using thermionic emitters [1].

Even though numerous problems are associated with the use of thermionic emitters, these problems are more easily solved than those associated with fabricating field effect electron emitters in the sizes required for the vast majority of electron tubes. In order to obtain field effect emission from point sources at reasonable field

levels, the radius of the point must be very small. This results in a small current from each point source even though the current density of the point is greater than 100 A-cm$^{-2}$ [2]. The major problem can be simply illustrated by considering the parameters involved in an electron source capable of emitting sufficient electrons for an overall current density of 1 A-cm$^{-2}$.

$J_f$ = 100 A-cm$^{-2}$ - fiber current density

d = $2 \times 10^{-5}$ cm - fiber diameter

J = 1 A-cm$^{-2}$ - total current density

$A_f$ = $3.14 \times 10^{-10}$ cm$^2$ - fiber area

N = number of fibers required

$$N = \frac{J}{J_f A_f}$$

N = $3.185 \times 10^7$ fibers-cm$^{-2}$

In the above example, it is assumed that all fibers are emitting with the same current density and that the current density is uniform across the face of the total emitter. This requirement further complicates the problem because it requires that the fibers all be the same diameter, be evenly spaced, and be the same distance from the anode.

Recent advances in the techniques for growing oxide-metal composites have resulted in a material that appears to meet the requirements for a field effect electron emitter. This material, in its final form, consists of metal rods or fibers separated by an insulating oxide as shown in Figure 1 [3]. The fibers are composed of metal conductors such as tungsten, and the insulating oxide can be any number of oxides such as uranium or zirconium which are compatible with the system. It has been demonstrated that this material can be grown with the required number of fibers per unit area with diameters sufficiently small to operate as a field effect emitter at moderate electric fields.

The field effect electron emitter consists of an oxide-metal composite as shown in Figure 1. The metal fibers are grown in place. The diameter of the fibers and number of fibers are functions of the growth rate and the oxide-metal ratio, and they are controllable over a large range. The majority of the fibers are continuous, and the reverse side of the composite can be joined to a backing plate to insure thermal and electrical conductivity.

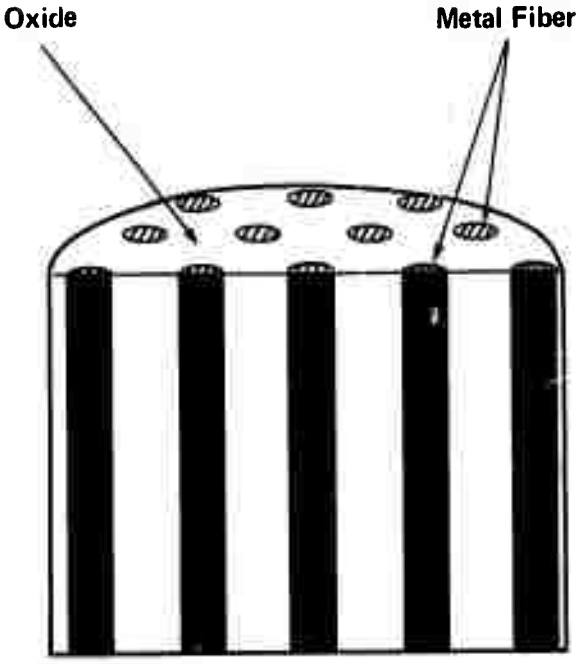


Figure 1. Oxide-Metal Composite for Field Effect Emission

The oxide-metal composite field effect electron emitter is adaptable to many configurations for various applications. Because the resistivity of the oxide is much greater than the resistivity of the metal, the composite operates as a field effect emitter in the configuration shown in Figure 1, and it is not necessary for the metal fibers to extend above the oxide. The advantages of this configuration are simplicity, ruggedness, and cost reduction. This type electron emitter is easily aligned in the system.

In order to promote electron emission at lower field values, the oxide can be etched below the surface of the metal fiber and the metal fiber sharpened as shown in Figure 2. This configuration will emit electrons at a lower field. However, it has the disadvantages of being more fragile, and the total emission may be limited due to the reduced area of the fiber tips.

A third example consists of etching the metal fibers below the surface of the oxide as shown in Figure 3. This configuration results in a rugged structure that is easily aligned in the device, and it has the proper configuration for either placing the collector in contact with the oxide surface or plating an accelerating anode on the oxide and having a collector at the same or a different potential.

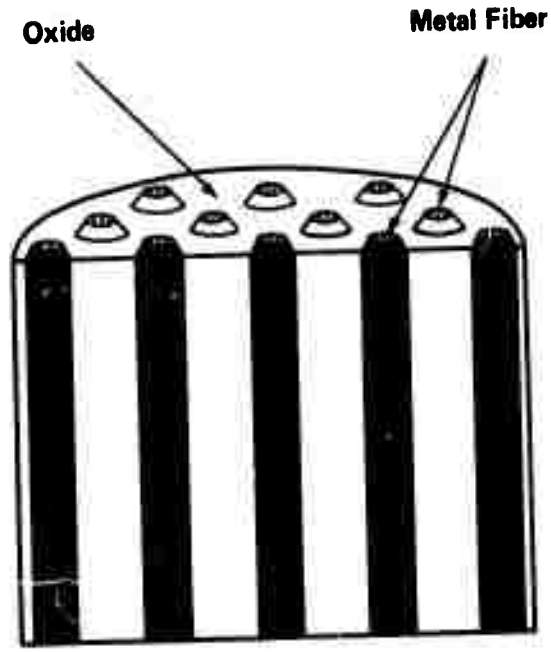


Figure 2. Oxide-Metal Composite with Oxide Etched Below Fibers and Fibers Sharpened

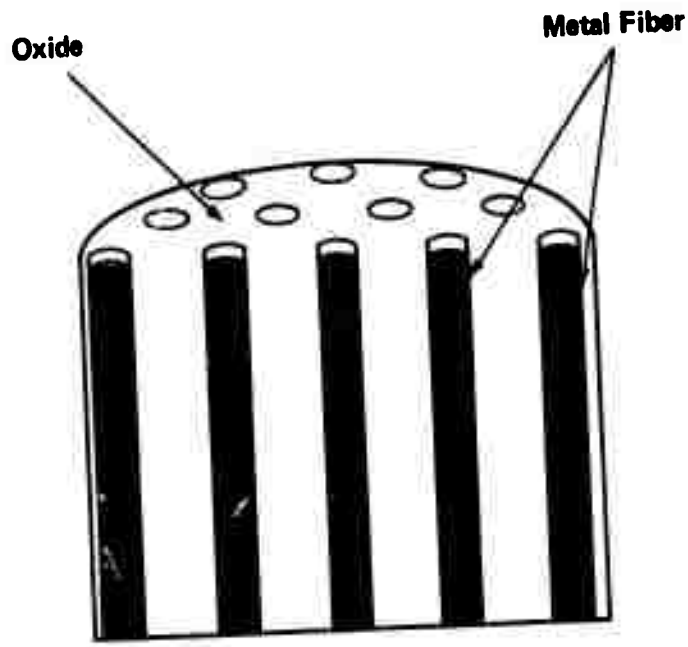


Figure 3. Oxide-Metal Composite with Metal Fibers Etched Below Oxide Surface

A graph of the current density versus applied voltage for a diode with a field effect electron emitter is shown in Figure 4. These results agree with data collected from solid metal systems and result in a straight line when Log J versus electrode spacing with a constant applied voltage is plotted as shown in Figure 5 [3].

The field effect electron emitter will probably be most used as a replacement for thermionic emitters in the future, but it will not be limited to this application. The shape of the current density versus field or applied voltage is such that it will be of interest in the development of new components. For instance, in a diode configuration, the device can be used as a completely passive over-voltage protection device until its operation is required [4]. At low voltages no current flows, while at high voltages the device becomes essentially a short circuit for the system. The device may also find application as a high voltage rectifier, as a voltage regulator component, and as a pulse shaping device [5, 6].

Since the use of a melt-grown oxide-metal composite as a field effects electron emitter is a relatively new idea, much data concerning the ideal composition as well as physical properties are needed. Some areas of immediate interest are the optimum fiber spacing, diameter, and height for field effect emission, as well as optimum fiber and oxide composition. The data collected to date have been from tungsten, which has a high work function compared to some tungsten alloys. Therefore, it should be possible to obtain the same current density at lower fields by using a tungsten alloy.

## 3. CONCLUSIONS

Several of the above-mentioned parameters are now being considered under the sponsorship of Materials Sciences, Advanced Research Projects Agency. As soon as samples of the material became available, it was evaluated for use as a field effect emission due to the demonstrated need for such a device, but its applications are by no means limited to this single device. By varying compositions, it has potential as a thermionic emitter, as a variable impedance, and possibly in solid state devices. As an oxide-metal composite, it has the corrosion and heat resistance of the oxide with the greater thermal conductivity due to the metal fibers. The metal fibers should also increase the strength and shock resistance over that found in a pure oxide component.

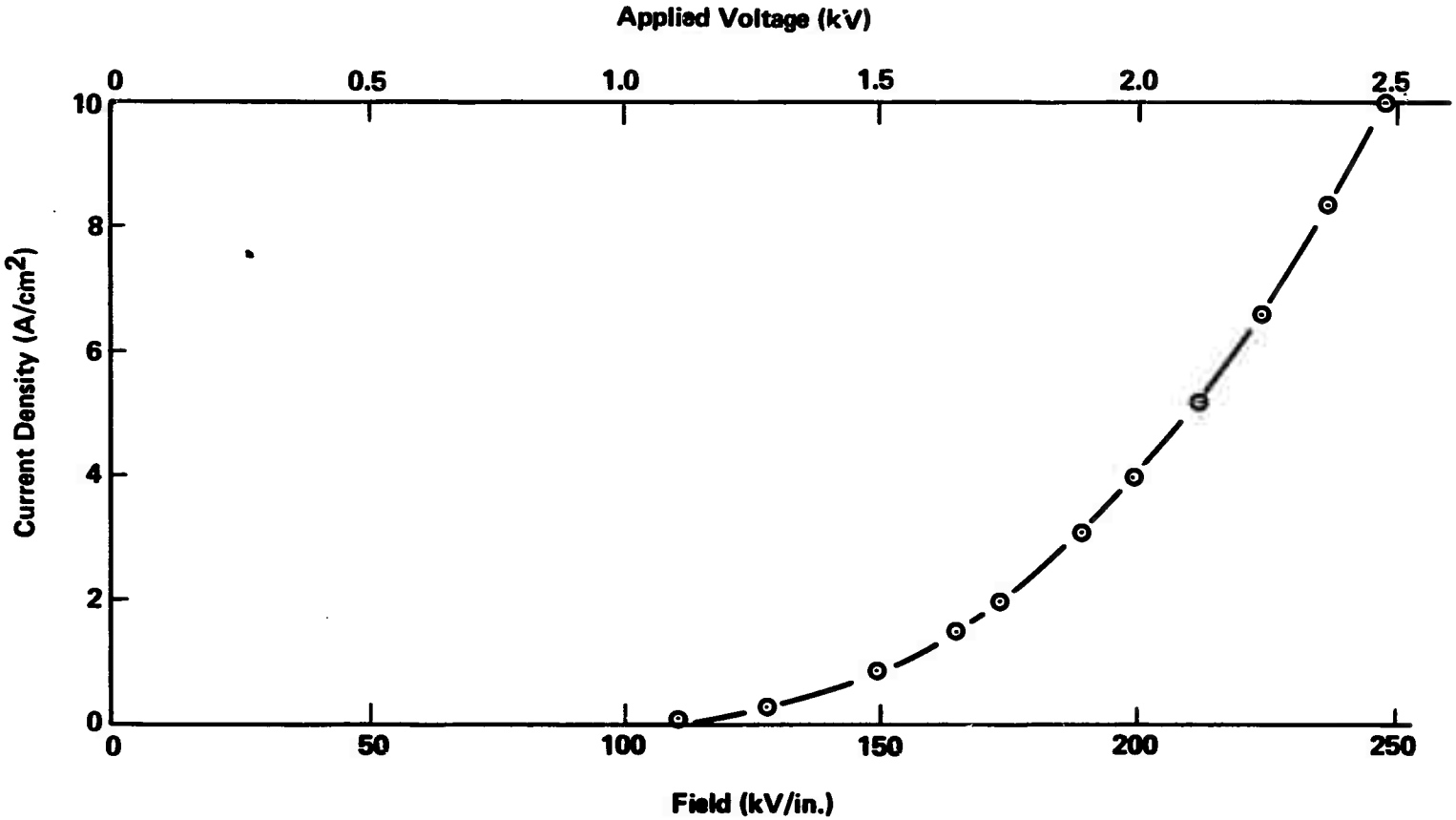


Figure 4. Applied Voltage or Electric Field Versus Current Density

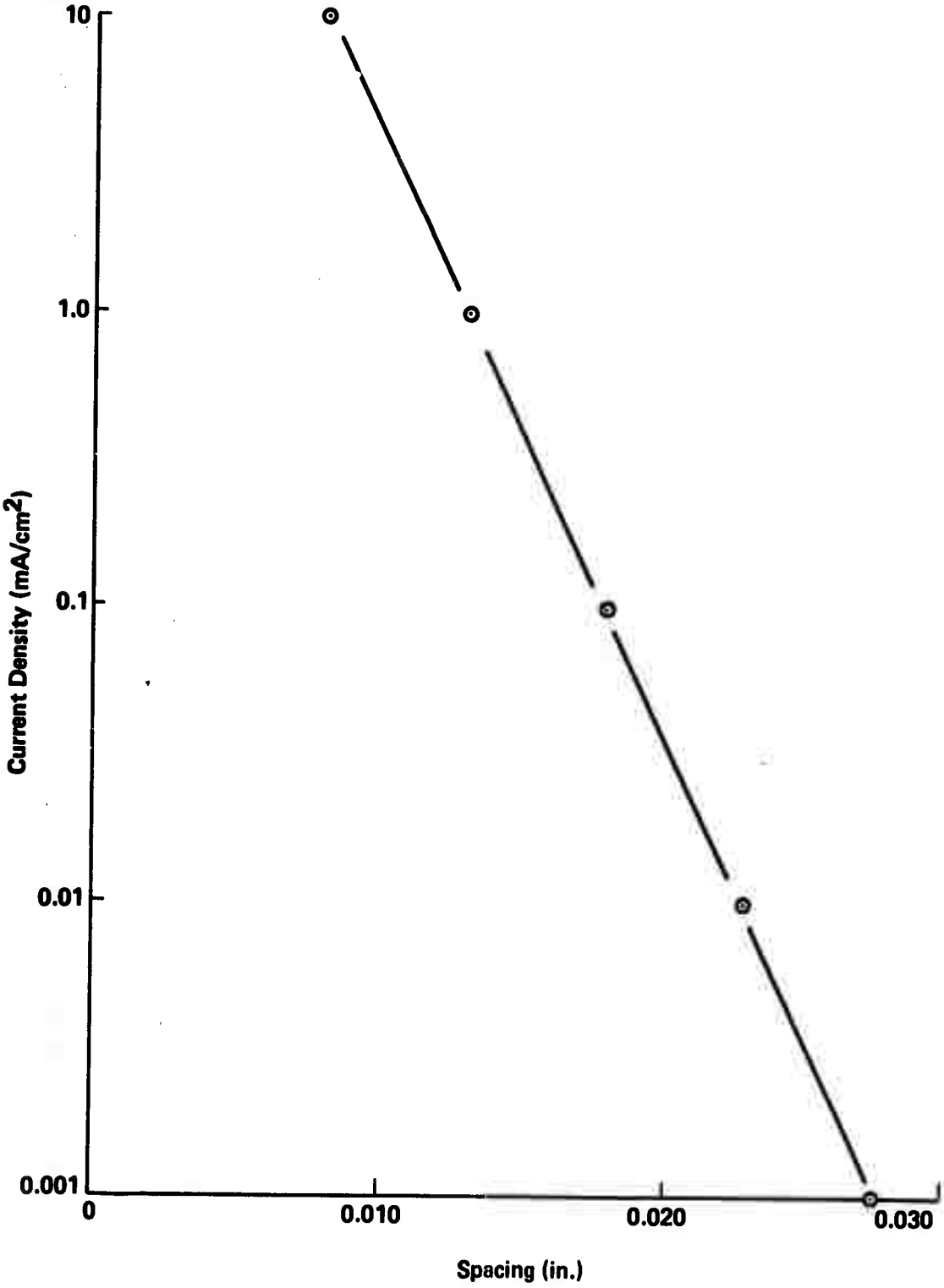


Figure 5. Spacing Versus Current Density with Fixed Applied Voltage

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